

C wherein said apparatus further comprises means for calculating a temperature dependence of non-uniformity of the static magnetic field in the inspection space, said non-uniformity distribution of the static magnetic field being caused by temperature change of the static magnetic field generating unit and/or surroundings thereof;

means for holding a control data for correcting the non-uniformity of the static magnetic field corresponding to the temperature; and

means for outputting the control data being selected from said control data holding means based on the detected temperature into said control unit.

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### REMARKS

Claims 1-31 are rejected. Claims 1-13 are herein canceled without prejudice. Claim 31 is herein amended to correct the claim numbers from which claim 31 depends. No new matter has been introduced.

Claims 14-31 are pending.

### Claim Rejections under 35 U.S.C. §103

Claims 1-31 are rejected under 35 U.S.C. §103(a) as being allegedly unpatentable over *Yamaguchi et al.* (U.S. Patent No. 4,663,592; hereafter "*Yamaguchi*") in view of *Warner* (GB 2 219 406; hereafter "*Warner*").

Applicant respectfully disagrees with the rejection.

The present invention provides an MRI apparatus which comprises: a static magnetic field generating unit; a gradient magnetic field generating unit; a high frequency magnetic field generating unit; a nuclear magnetic resonance signal-detecting unit; a display unit; a temperature detecting unit; a magnetic field correcting unit; and a control unit for the magnetic field correcting unit (*see*, in particular, claims 1, 14, 23, and 30; Figures 1 and 7). The MRI apparatus of the present invention provides a mechanism that can ***stably maintain the uniformity of the magnetic field*** regardless of the temperature variations in the static magnetic field and/or its surrounding space, and/or influence by the magnetization factor of

the examination area of the subject examined. Such stable maintenance of uniform magnetic field is achieved, in particular, by the magnetic field correcting unit and the control unit for the magnetic field correcting unit.

“Uniformity” or “non-uniformity” of the magnetic field referred to in the present specification and, therefore, in all present claims, is *the sum of the uniformity or non-uniformity of each component, i.e.,* a linear term component of  $y$  ( $y$  component) and a quadratic term component of  $z$  ( $z^2$  component) with regard to the first embodiment (*see* page 12, lines 10-13; and Figures 1-6, of the present specification) and, in addition, a quartic term component of  $z$  ( $z^4$  component) with regard to the second embodiment (*see* page 23, lines 1-6).

The magnetic field correcting system comprises one or more thermometers 13 that detect temperature and output electric signals corresponding to the detected temperature, a shim power source 14 that changes its output current based on the output signal value of the thermometer 13, and a shim coil 15 that generates a correction magnetic field (additional magnetic field) when the output current from the shim power source 14 is applied to the shim coil 15 (page 11, lines 1-7; and page 21, lines 7-20). The shim coil 15 consists of one or a plurality of coils *that include a coil that generates a magnetic field of the  $z^2$  term and a coil that generates a magnetic field of the  $z^4$  term*. The gradient magnetic field coil 3 may also function as the shim coil that generates a compensation magnetic field of a linear term (*see* page 11, lines 10-17; page 21, lines 21-26).

The temperature characteristic of the *magnetic field error component that causes the magnetic field non-uniformity* is measured (step 27 in Figure 2) in advance by obtaining the relationship between the temperature of an iron yoke 17 (static magnetic field generating magnet) and each of the magnetic field error components and that between the difference of temperature between the iron yoke 17 and the connection pipe 19', and each error component. Namely, for the temperature of the iron yoke 17, the non-uniformity (error) caused by temperature variation is measured *for each component corresponding to each shim coil*. The non-uniformity (error) caused by the temperature difference between the iron yoke 17 and the connector pipe 19' is measured likewise (page 21, line 27 through page 23, line 18; *also see* Figures 3, 4, and 8-10).

Based on the temperature characteristic of *each error component* thus obtained, the shim current that generates a correcting magnetic field to *cancel out each error component*, is calculated and supplied to each shim coil (steps 31 and 32 in Figure 2), thereby correcting *the sum of the non-uniformity of the magnetic field* and providing the uniform magnetic field. Thus, the MRI apparatus of the present invention is capable of coping with complex and sudden temperature changes in a short time, thereby increasing the reliability of the MRI examination data and reducing the imaging time for a patient.

*Yamaguchi* discloses an NMR image forming apparatus which comprises a frame, at least one magnetic coil that forms a static magnetic field; current means that supplies current to the magnetic coil; cooling means for the magnetic coil, at least one RF coil, RF current means that supplies current to the RF coil; detector means that detects temperature changes of the magnetic coil, cooling means, and/or the frame; and control means that adjusts, in response to the temperature changes detected by the detector means, a current source “to produce a constant *magnetic field intensity* on the subject, or adjusting the RF current applied to an RF coil, or mathematically adjusting the results” (see claims 1 and 2; Figures 1 and 5, col. 2, lines 21-41; and col. 5, lines 25-33) (emphasis added).

*Warner* discloses an electromagnet having at least first and second spaced windings and ferromagnetic annuli arranged to provide a field having a predetermined homogeneity in a central region, control means that enables the *total field to be controlled to any suitable predetermined value*; and thermal sensors in the annuli that are arranged in feed back circuitry controlling the winding so as to compensate for variations in the effect of the annuli (Claims 12-15; and Abstract).

In the Office Action, independent claims 1, 14, 23 and 30 of the present invention are rejected because, in particular, according to the Examiner, “the teaching [of *Yamaguchi*] . . . suggests that when variations in the static magnetic field  $H_0$  occur due to temperature variation the above described embodiment will react and cause the magnetic fields to be applied, at a constant intensity, by controlling the value of the current. This teaching suggests that at least one additional magnetic field is applied to keep the static magnetic field  $H_0$  constant.” Furthermore, the Examiner states that *Warner* also teaches a mechanism which generates an additional controlling magnetic field in response to the temperature changes detected by a temperature sensor.

Applicant respectfully traverses the statement.

As described above, *Yamaguchi* discloses a correction of *the intensity of the static magnetic field* corresponding to the temperature change of the MIR apparatus. In other words, *Yamaguchi* teaches an apparatus with a control means that minimizes the *fluctuations in the magnetic field intensity  $H_0$  (i.e., increase or decrease in intensity of the static magnetic field)*, due to temperature changes on the NMR image. However, the reference does not teach that the variations in temperature cause non-uniformity of the static magnetic field. Moreover, it does *not* teach or even suggest a means to *correct the non-uniformity* of the static magnetic field, rather than intensity of it. For example, as in the first embodiment (Figure 1) of *Yamaguchi*, it is clear that the intensity of the magnetic field is reduced due to the heat expansion of coils 1 and the enlargement of an interval between magnet coils (column 2, lines 52-61). The correction here is carried out by detecting a temperature change using temperature detecting devices 11-16 placed on the magnet coils 1, frames 3 and around the magnet, and controlling current I supplies the additional current to the magnetic coils so as to simply compensate the decrease of intensity in accordance with changes in temperatures of the magnetic coils and/or the frames based on data of the temperature detecting devices (column, lines 30-39). Such controls of the current result in *mere increase or decrease of the magnetic field* but *not* in correction of non-uniformity of the magnetic field by *correcting each error component contributing to the non-uniformity*.

*Warner* discloses electromagnets provided with temperature sensors on ferromagnetic annuli 3, 4. The magnetic field produced by at least one control winding may be arranged to cancel accurately the magnetic field change caused by temperature variations in at least one ferromagnetic means (page 6, lines 2-6). According to *Warner*, the current applied to the control winding is arranged to vary according to the value of the sensing by the temperature sensor and the magnetic field change is thereby maintained within 0.1 ppm even if the environment temperature changes by 10°C (page 5, line 33 through page 6, line 10). However, as in *Yamaguchi*, correcting means of *Warner* simply compensates the *electromagnet's total magnetic field, i.e., the magnetic field intensity* (see, for example, Abstract; page 4, lines 27 and 34-36; page 5, lines 3-5 and 26-32; page 6, lines 7-10, etc.). Thus, this reference does not teach or even suggest non-uniformity of the static magnetic field caused by the temperature change, or a way to correct such non-uniformity by

compensating each error component with the corresponding shim coil as in the present invention.

Although, in the items 14 and 15 of the office action, the Examiner notes that new claims 14 and 23 are just another version of claim 1, Applicant submits that claims 14 and 23 clearly recite the non-obvious feature of the invention discussed above, *i.e.*, “a magnetic field correcting unit for generating an additional magnetic field for correcting ***non-uniformity of said static magnetic field being caused by temperature change*** of said static magnetic field generating unit and/or surrounding space of it”, which is not taught or suggested at all by either reference alone or in combination as discussed above.

In addition, the Examiner notes, with regard to the additional limitations in claim 23, that *Yamaguchi* “teaches, suggests and shows ‘said static magnetic field generating unit comprising’ at least ‘a pair of superconducting coils and a pair of cryostats each accommodating one of said pair of superconducting coils’” and a supporting means “for supporting said pair of cryostats as being apart so as to form an inspection space for an object to be examined.” However, Applicant respectfully submits that the examiner’s interpretation of the reference is in error, because *Yamaguchi* discloses a coil array that has ***a tunnel shape***, and the inspection space is formed inside the tunnel (*see* Figure 2). On the other hand, the MIR apparatus recited in claim 23 of the present invention comprises a pair of coils that are ***supported by a supporting means*** so that they are separated with a certain spatial gap between them and an inspection space is formed between the coils. Namely, the apparatus of *Yamaguchi* does not teach nor imply non-uniformity caused by expansion and contraction of such supporting means due to the temperature change, or a mechanism to correct such non-uniformity.

The Examiner also regards new claim 30 as another version of claim 23 and notes that “*Yamaguchi et al.*, teaches, suggest and show the limitation,” that is, “correcting non-uniformity, of said static magnetic field being caused by deformation of aid supporting means due to the temperature change of said static magnetic field generating unit and/or surrounding space of it.” However, as discussed above, this reference teaches that heat expansion of the coils and frames causes ***fluctuations in the intensity*** of the generated static magnetic field, but it does ***not*** teach ***non-uniformity*** caused by deformation of the supporting means.

The same argument is applicable to the claims that depend from 14, 23 and 30 as well as remaining independent claims 21, 22 and 30, all of which recite this unique feature of the present invention.

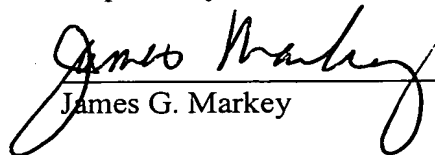
Thus, the present claims are not obvious over *Yamaguchi* in view of *Warner*. Nevertheless, Applicant herein cancel claims 1-13 without prejudice solely to accelerate the prosecution of the case and expedite the allowance of claims to certain embodiment of the invention. Applicants reserve all rights to pursue the broader subject matter in a continuation application.

Accordingly, Applicant believes that all pending claims 14-31 are now in condition for allowance, early notification of which is earnestly requested.

No fee, other than the extension fee, is believed to be due for this amendment. Should any fee be required, please charge such fee to Deposit Account No. 16-1150.

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Respectfully submitted,

  
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Attachments

**EXHIBIT A**  
**MARKED-UP VERSION OF THE AMENDED CLAIM**  
**(FILED APRIL 16, 2003)**  
**U.S. PATENT APPLICATION SERIAL NO. 09/535,241**

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Cancel claims 1-13.

31. (Amended) A magnetic resonance imaging apparatus according to any one of claims [1, 13,] 14, 23 and 30;

wherein said apparatus further comprises means for calculating a temperature dependence of non-uniformity of the static magnetic field in the inspection space, said non-uniformity distribution of the static magnetic field being caused by temperature change of the static magnetic field generating unit and/or surroundings thereof;

means for holding a control data for correcting the non-uniformity of the static magnetic field corresponding to the temperature; and

means for outputting the control data being selected from said control data holding means based on the detected temperature into said control unit.



**EXHIBIT B**

**A LIST OF PENDING CLAIMS AFTER ENTRY OF THE PRESENT APPLICATION  
(FILED APRIL 16, 2003)**

**U.S. PATENT APPLICATION SERIAL NO. 09/535,241**

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14. A magnetic resonance imaging apparatus comprising:
  - a static magnetic field generating unit for generating a homogeneous static magnetic field in an inspection space;
  - a gradient magnetic field generating unit for generating a magnetic field strength gradient;
  - a high frequency magnetic field generating unit;
  - a detecting unit for detecting nuclear magnetic resonance signals generated from an object to be examined;
  - a display unit for displaying an image as a result based on the detection;
  - a temperature detecting unit for detecting a temperature of said static magnetic field generating unit and/or surroundings thereof;
  - a magnetic field correcting unit for generating an additional magnetic field for correcting non-uniformity of said static magnetic field being caused by temperature change of said static magnetic field generating unit and/or surrounding space of it; and
  - a control unit for controlling said magnetic field correcting unit based on the temperature detected by said temperature detecting unit.
15. A magnetic resonance imaging apparatus according to claim 14,  
wherein the control unit has a temperature setting unit that sets a temperature detected by the temperature-detecting unit.
16. A magnetic resonance imaging apparatus according to claim 14,  
wherein the temperature detecting unit detects temperatures of at least two positions.
17. A magnetic resonance imaging apparatus according to claim 14,  
wherein the magnetic field correcting unit comprises a shim coil for generating an additional magnetic field and a shim power source that supplies a current to the shim coil.



18. A magnetic resonance imaging apparatus according to claim 14,  
wherein the control unit comprises a voltage generating unit that generates a voltage corresponding to a non-uniformity component of the magnetic field at the temperature detected by the temperature detecting unit, a voltage/current converter that converts the voltage output by the voltage generating unit to current, and a supplying unit that supplies to the magnetic field correcting unit the current generated from the voltage/current converter.

19. A magnetic resonance imaging apparatus according to claim 14,  
wherein the magnetic field correcting unit generates at least one additional magnetic field of linear term of  $y$ , quadratic term of  $z$  and quartic term of  $z$ , where  $z$  is the direction of the static magnetic field and  $y$  is one direction orthogonal to  $z$ .

20. A magnetic resonance imaging apparatus according to claim 14,  
wherein the temperature detecting unit is disposed near the static magnetic field generating unit and/or in a room where the static magnetic field generating unit is placed.

21. A method for maintaining uniformity of a static magnetic field generated by a static magnetic field generating unit in a magnetic resonance imaging apparatus, by generating an additional magnetic field, the method comprising the steps of:

calculating a temperature dependence of non-uniformity of the static magnetic field in an inspection space for an object to be examined, said non-uniformity distribution of the static magnetic field being caused by temperature change of the static magnetic field generating unit and/or surroundings thereof; and

detecting a temperature of the static magnetic field generating unit and/or surroundings thereof; and

generating the additional magnetic field having a magnetic field distribution for correcting said nonuniformity of the static magnetic field based on the detected temperature.

22. A magnetic resonance imaging apparatus comprising:  
a static magnetic field generating means for generating a homogeneous static magnetic field in an inspection space; and

an uniformity correcting means for detecting temperature change affecting the uniformity of the static magnetic field generated by the static magnetic field generating means and for generating an additional static magnetic field for canceling non-uniformity of the static magnetic field based on the detected temperature change.

23. A magnetic resonance imaging apparatus comprising:

a static magnetic field generating unit for generating a static magnetic field of a predetermined intensity, said static magnetic field generating unit comprising a pair of superconducting coils and a pair of cryostats each accommodating one of said pair of superconducting coils;

a supporting means for supporting said pair of cryostats as being apart so as to form an inspection space for an object to be examined;

a gradient magnetic field generating unit for generating a magnetic field having an intensity gradient;

means for generating a high frequency magnetic field;

means for detecting nuclear magnetic resonance signals generated from said object;

means for processing said nuclear magnetic resonance signals and for displaying the processed results;

a temperature detecting unit for detecting a temperature of said static magnetic field generating unit and/or surroundings thereof;

a magnetic field correcting unit for generating an additional magnetic field for correcting non-uniformity of said static magnetic field being caused by temperature change of said static magnetic field generating unit and/or surrounding space of it; and

a control unit for controlling said magnetic field correction unit based on the temperature detected by said temperature detecting unit.

24. A magnetic resonance imaging apparatus according to claim 23,

wherein the control unit has a temperature setting unit that sets a temperature detected by the temperature-detecting unit.

25. A magnetic resonance imaging apparatus according to claim 23,

wherein the temperature detecting unit detects temperatures of at least two positions.

26. A magnetic resonance imaging apparatus according to claim 23,  
wherein the magnetic field correcting unit comprises a shim coil for  
generating an additional magnetic field and a shim power source that supplies a current to the  
shim coil.

27. A magnetic resonance imaging apparatus according to claim 23,  
wherein the control unit comprises a voltage generating unit that generates a  
voltage corresponding to a non-uniformity component of the magnetic field at the  
temperature detected by the temperature detecting unit, a voltage/current converter that  
converts the voltage output by the voltage generating unit to current, and a supplying unit that  
supplies to the magnetic field correcting unit the current generated from the voltage/current  
converter.

28. A magnetic resonance imaging apparatus according to claim 23,  
wherein the magnetic field correcting unit generates at least one additional  
magnetic field of linear term of  $y$ , quadratic term of  $z$  and quartic term of  $z$ , where  $z$  is the  
direction of the static magnetic field and  $y$  is one direction orthogonal to  $z$ .

29. A magnetic resonance imaging apparatus according to claim 23,  
wherein the temperature detecting unit is disposed near the static magnetic  
field generating unit and/or in a room where the static magnetic field generating unit is  
placed.

30. A magnetic resonance imaging apparatus comprising:  
a static magnetic field generating unit for generating a static magnetic field of  
a predetermined intensity, said static magnetic field generating unit including a pair of  
superconducting coils;  
a supporting means for supporting said pair of superconducting coils as being  
apart so as to form an inspection space for an object to be examined;  
a gradient magnetic field generating means for generating a magnetic field  
having an intensity gradient;  
means for generating a high frequency magnetic field;  
means for detecting nuclear magnetic resonance signals generated from said  
object;

means for processing said nuclear magnetic resonance signals and for displaying the processed results;

a temperature detecting unit for detecting a temperature of said static magnetic field generating unit and/or surroundings thereof;

a magnetic field correcting unit for generating an additional magnetic field for correcting non-uniformity of said static magnetic field being caused by deformation of said supporting means due to the temperature change of said static magnetic field generating unit and/or surrounding space of it; and

a control unit for controlling said magnetic field correction unit based on the temperature detected by said temperature detecting unit.

31. (Amended) A magnetic resonance imaging apparatus according to any one of claims 14, 23 and 30;

wherein said apparatus further comprises means for calculating a temperature dependence of non-uniformity of the static magnetic field in the inspection space, said non-uniformity distribution of the static magnetic field being caused by temperature change of the static magnetic field generating unit and/or surroundings thereof;

means for holding a control data for correcting the non-uniformity of the static magnetic field corresponding to the temperature; and

means for outputting the control data being selected from said control data holding means based on the detected temperature into said control unit.